JOINT INSTITUTE FOR NUCLEAR RESEARCH

Dzhelepov Laboratory of Nuclear Problems

FINAL REPORT ON THE SUMMER STUDENT PROGRAM

Data analysis of the components for the production of the Micromegas detectors at the ATLAS experiment at CERN

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Abstract

The ATLAS experiment at CERN is undergoing an upgrade. In this upgrade the Small Wheels, which presently consist of muon detectors, will be replaced. In the new Small Wheels, the Micromegas detectors will be implemented. The Dzhelepov Laboratory of Nuclear Problems (DLNP) in the Joint institute for nuclear research (JINR) is making these detectors for CERN. They consist of PCB panels that have very strict requirements for the resolution that should be lower than $100\mu m$, which corresponds to a more precise resolution. The planarity of the PCB panels is transferred from the granite table using a vacuum. In my project I was working on the data sets describing the surfaces of PCB panels and the granite table. The task was to clean up these data sets of outliers and to fit the data. In this report I present my results.

Contents

1 Introduction

The European Organization for Nuclear Research (CERN) was founded in 1952 to conduct fundamental physics research. It is located at the French Swiss border near the city of Geneva. It currently has 22 member states that work together on many particle physics experiments. The Dzhelepov Laboratory of Nuclear Problems (DLNP) participates in production of experimental components for CERN.

DLNP has a crucial role in mass production of Micromegas chambers that will be used in the New Small Wheel (NSW) for the ATLAS experiment at CERN. The Institute's contribution is the production and testing of 64 double-sided readout panels, as well as the assembly and testing of 32 quadruplets with the drift panels, produced at Aristotle University of Thessaloniki. Finally, all produced and tested chambers will be shipped to CERN.

One of the elements to take into account in the production of these panels is the surface planarity requirement, this one should be known with root mean square error of less than $80\mu m$ over $3m^2$ surface, which will be the main study subject in this work.

1.1 The Large Hadron Collider (LHC)

The Large Hadron Collider (LHC) is the biggest and most powerful particle collider in the world. A collider is a machine that accelerates two beams of particles that by collision decay and make byproducts that scientist try to detect in order to prove a physics theory or discover something that wasn't even hypothesized.

The LHC was built by CERN and it took 10 years to construct the apparatus (finished in 2008). It is a huge international project that includes collaborations of thousands of engineers and scientists from all around the world.

The collider has four crossing points, where seven detectors are positioned, each of which designed for a certain kind of research. The four largest experiments are ATLAS, CMS, ALICE and LHCb as shown in Figure 1. The purpose of the detectors is to discover particles that are smaller then an atom. Initially, the main focus of ATLAS and CMS was to discover the existence of the Higgs boson, a key part of the Standard Model of physics, which was only a theoretical particle.

The data created at the LHC is processed at the biggest computing grid in the world. The reason why such a grid is needed is because just in one year the LHC produces tens of petabytes that need to be analyzed.

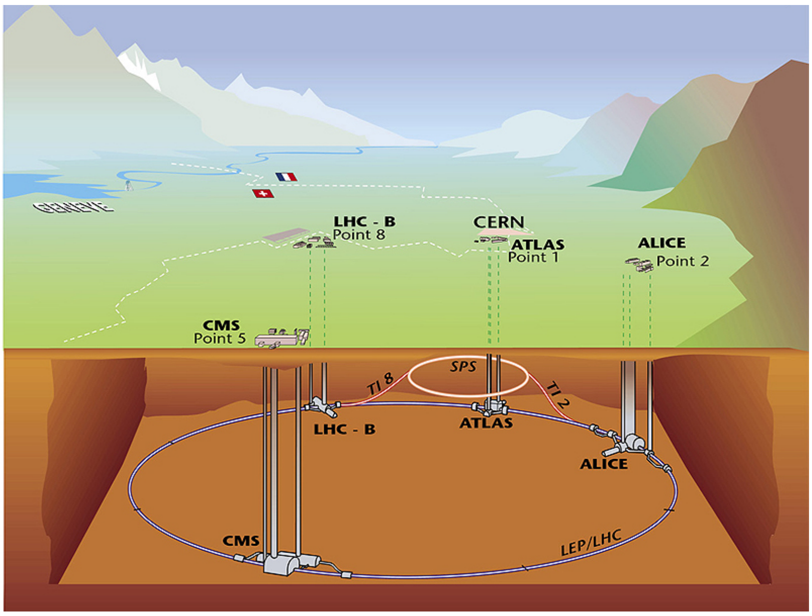


Figure 1: The LHC complex at CERN.

1.2 The ATLAS experiment

ATLAS [1] is one of the four major experiments at the Large Hadron Collider (LHC) at CERN. It is a general-purpose particle physics experiment run by an international collaboration and, together with CMS, is designed to exploit the full discovery potential of the huge range of physics opportunities that the LHC provides[3].

ATLAS physicists test the predictions of the Standard Model, which encapsulates our current understanding of what the building blocks of matter are and how they interact. These studies can lead to ground-breaking discoveries, such as the Higgs boson, physics beyond the Standard Model and the development of new theories to better describe our universe[6].

A schema of the ATLAS detector is shown in Figure 2. ATLAS is $46m$ long, $25m$ high and $25m$ wide and it is the largest experiment at the LHC, but also the largest experiment ever built. It is located in a cavern $100m$ underground at CERN. As many high energy physics detectors, it is constructed with muon detectors, calorimeters and magnets, etc. The focus of this study is related to production of the New Small Wheels for the ATLAS (marked red in Figure 2).

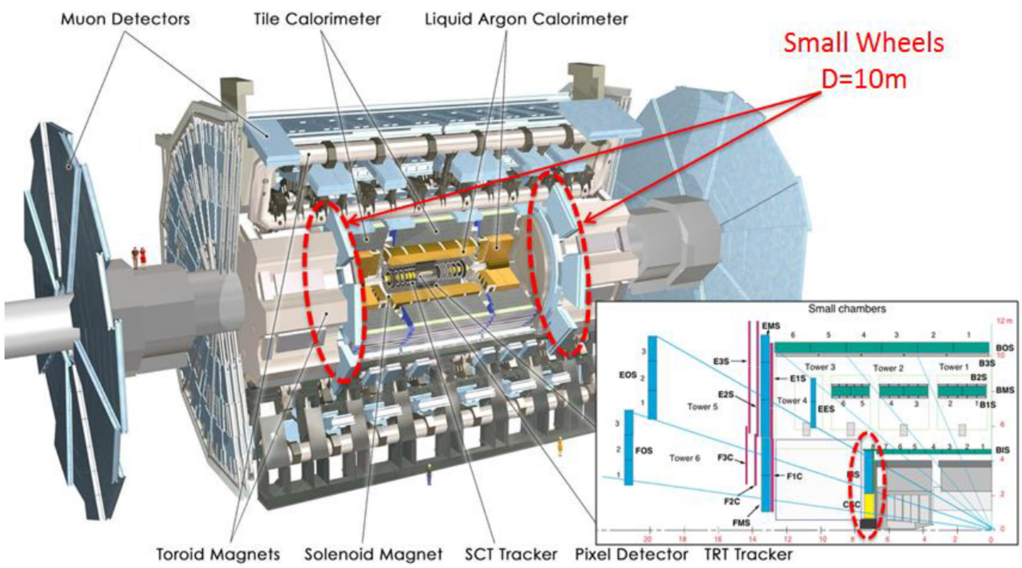


Figure 2: The ATLAS experiment at CERN.

1.3 The experiment upgrade

The LHC time line is divided into periods of active running and long shutdowns. During the long shutdown in 2018 the ATLAS experiment is going to be upgraded for the Run III, which takes place in 2019 and 2020[5].

The first station of the muon end-cap (small wheel) at the ATLAS experiment needs to be replaced during the upgrade.The NSW will have to operate in a high background radiation region and at the same time reconstruct the muon tracks with high precision. These performance criteria are demanding. In particular, the precision reconstruction of the tracks for physics analysis requires a spatial resolution of about $100\mu m$ in addition to the requirements in the event selection (trigger) system[4].

The NSW will have two chamber technologies, one primarily devoted to the event selection (trigger) system and one dedicated to precision tracking (Micromegas detectors). The Micromegas detectors have exceptional precision tracking capabilities due to their small gap ($5mm$) and strip pitch (approximately $0.5mm$). Such precision is crucial to maintain the current ATLAS muon momentum resolution in the high background radiation environment of the upgraded LHC.

2 Statement of the Problem

The readout boards are the key elements of the Micromegas detectors. Their quality in terms of strip precision and electrical properties determine whether the detector will work properly or not. The readout strips are patterned on $0.5mm$ thick PCBs and then covered by a $64\mu m$ thick layer of insulator, followed by the resistive strips. The schema of internal structure of the Micromegas readout board is shown in Figure 3.

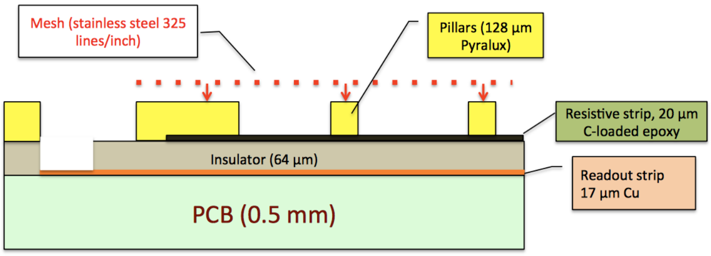


Figure 3: Internal structure of the Micromegas readout board and the placement of PCB.

The goal of this project is to analyze the data of the PCB planes and the granite table. The data describes the surface topography of the planes - its coordinates and its height. Measurement of the height can sometimes be wrong, and such (incorrect) heights need to removed. Finally, the task is to find the right fit for the data set. The data was measured on a CNC machine in Dubna. The machine is shown in Figure 4.

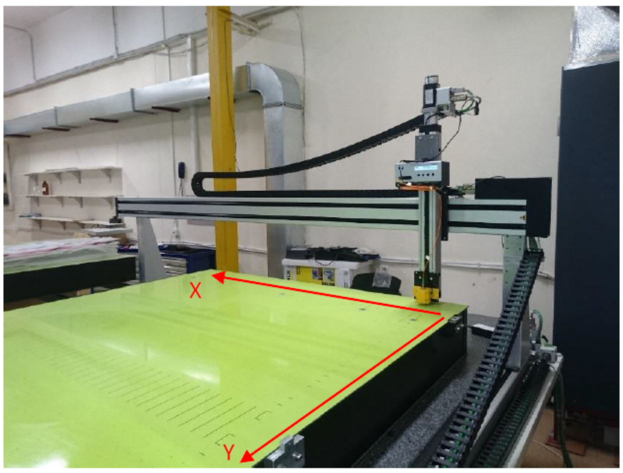


Figure 4: The optical probe measurement process on the vacuum tables.

3 Methodology

The data sets are presented as an array of entries: h, x, y. The first value is height (h), the second and the third are x and y coordinates, respectively. The data was recorded with the CNC machine so the x and y coordinates are the same in all data sets and have a pattern that is easy to recognize. First values of x and y are zero and increase with an arithmetic progression. For x the progression is $x_i = x_{i-1} + 11.19$ and for y is $y_i = y_{i-1} + 20$. The range of values of the x coordinate is from 0 to 2573.70 and the range of values of the y coordinate is from 0 to 2440. The range of values for heights is presented in the tables in the section 3.2 for each data set. The units of x, y are in mm and for h is in μm.

There is three data documents to analyze and modify. The first one is of a granite table, the second one is of one side of a PCB panel and the third one is of the opposite side of the PCB panel.

Initially, it appears that there are a lot of points that are just null (zeros) and those are the first to be removed. The second part of this study was to remove the points that were obviously far from the curved plane which was a bit more difficult to do. I removed those points using the program where I calculated local averages and standard deviations, which is explained in more detail below.

3.1 Data selection

In order to filter data sets from extreme values, I found the maximums, minimums, averages and standard deviations. These values are shown in the tables in section 3.2. However, global averages proved not to give optimal results, which is why I calculated the local averages for each section of the planes.

I divided the data set into eight sections by x axis and calculate average height(h_{avg}) and standard deviation(σ) for each one to get more precise values. In the appendix 7 I have put snippets of the code I used.

The data set was selected in a way that excluded points that do not fit into $h = h_{avg} \pm 2 * \sigma$ and also excluded zero values. This was done section by section. The new selection was saved into a new document.

3.2 Results

Below are tables with maximums, minimums, averages and standard deviations and comparisons of the data before and after the selection for all data sets. In reality, the panels appear completely flat. The plots are curved because of the oscillations of the CNC machine that recorded the panels. Also, the ROOT framework plots the data in a way that accents the curve.

3.2.1 PCB panel, side A

Shown in this table are the side by side comparisons of one side of the PCB panel (side A) data before and after the selection. The units of the height values are in μm.

PCB side A	original data set	cleaned data set
entries	13051	12782
average	809.016	808.43
minimum	82.89	255.13
maximum	1994.32	1880.8

In Figure 5 it is shown a graphical representation of the mentioned selection. x and y axis are coordinates in space in mm, while z is the height of the plane in μm.

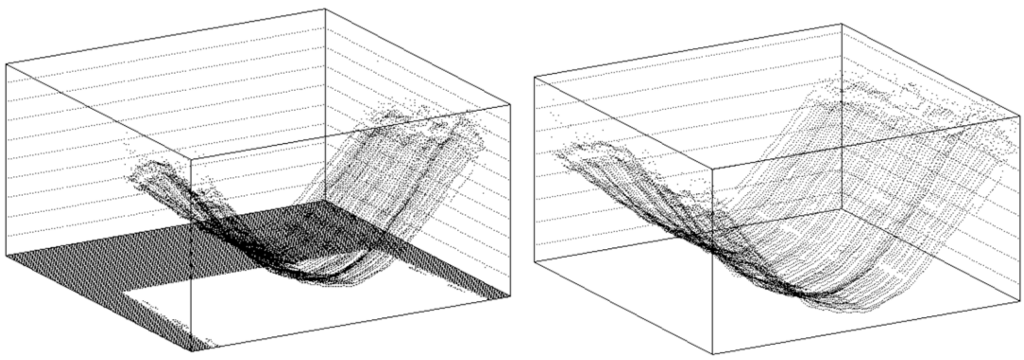


Figure 5: Side A of the PCB data before and after the selection of the data.

3.2.2 PCB panel, side B

Shown in this table are the side by side comparisons of the other side of the PCB panel (side B) data before and after the selection. The units of the height values are in μm.

PCB side B	original data set	cleaned data set
entries	13109	12766
average	796.03	793.846
minimum	33.51	231.02
maximum	1990.91	1775.82

In Figure 6 there is a graphical representation of the mentioned selection. x and y axis are coordinates in space in mm, while z is the height of the plane in μm.

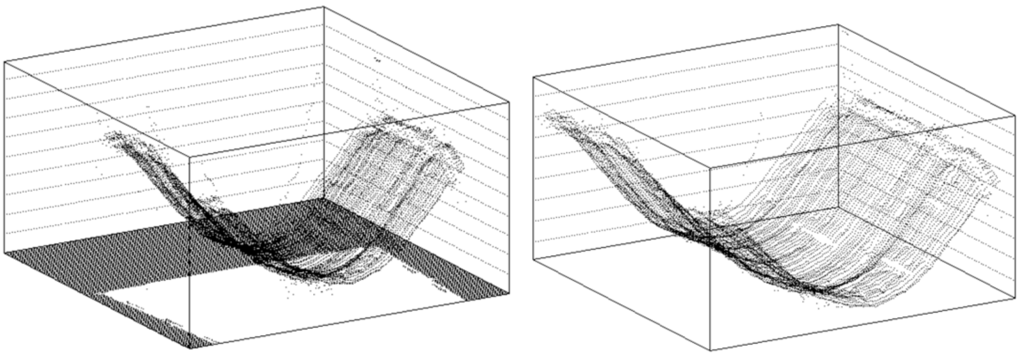


Figure 6: Side B of the PCB panel before and after the selection of the data.

3.2.3 Granite table

Shown in this table are the side by side comparisons of the granite table data before and after the selection. The units of the height values are in μm.

granite table	original data set	cleaned data set
entries	16594	16276
average	830.104	822.764
minimum	130.74	130.74
maximum	1908.57	1866.82

In Figure 7 there is a graphical representation of the mentioned selection. x and y axis are coordinates in space in mm, while z is the height of the plane in μm.

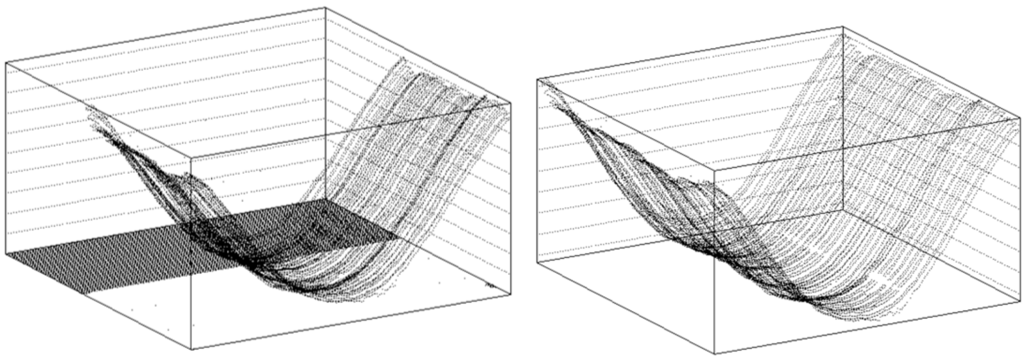


Figure 7: Granite table before and after the selection of the data.

3.2.4 Fit of the granite table

The data was processed, visualized and fitted with the ROOT framework [2]. ROOT is a C++ based software used for physics analyses at CERN. In Figures 8, 9 and 10 it is shown the 2D and 3D fits of the granite table.

3.2.5 2D fit

In order to have a better estimate and understanding for the potential 3D fit, I calculated a 2D fit for the granite table data set. This was quite helpful for estimating the 3D fit. My assumption was a polynomial fit:

$$h(x) = a_5 * x^5 + a_4 * x^4 + a_3 * x^3 + a_2 * x^2 + a_1 * x + a_0$$

where $a_0, a_1, a_2, a_3, a_4, a_5$ are coefficients that were calculated by the ROOT fit command. x and y axis are coordinates in mm, while z is the height of the plane in μm.

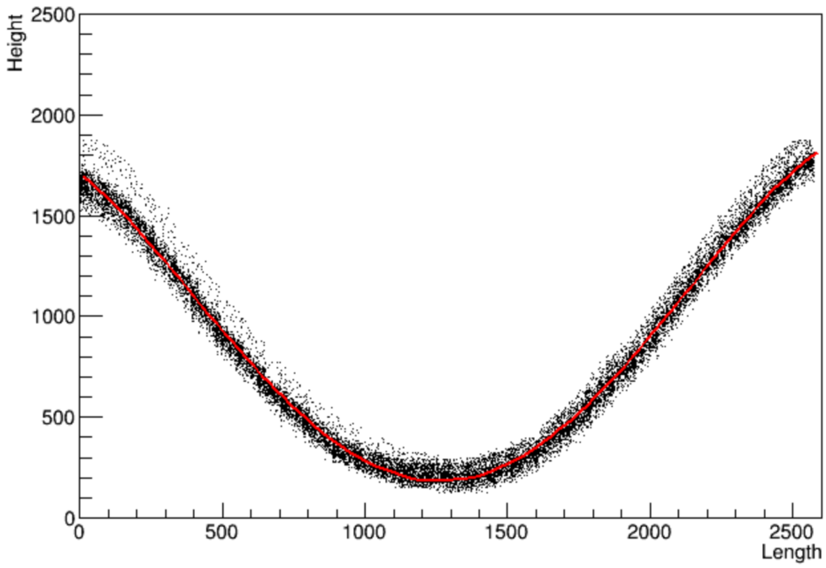


Figure 8: 2D fit of the granite table data; functional dependence h = h(x).

3.2.6 3D fit

Here is the 3D fit of the granite table. The assumed function of this plane is:

$$h(x, y) = -a_0 * x - a_1 * y - a_2$$

where a_0, a_1, a_2 are coefficients that were calculated by the ROOT fit command. x and y axis are coordinates in space in mm, while z is the height of the plane in mm.

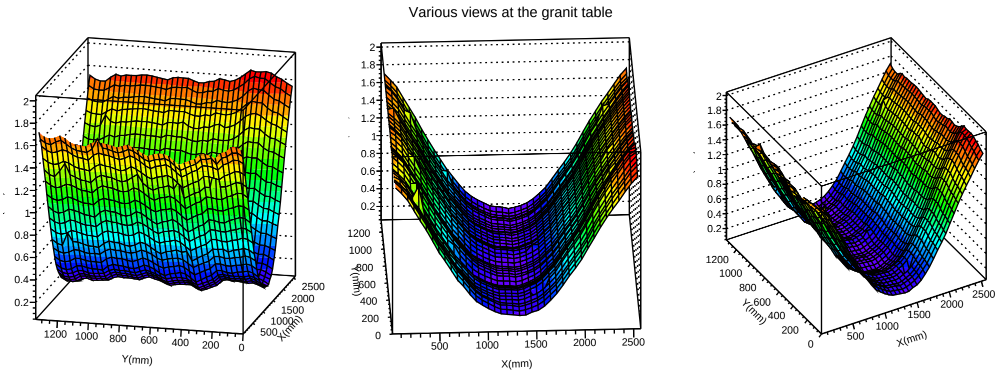


Figure 9: 3D fit and the three views of the granite table.

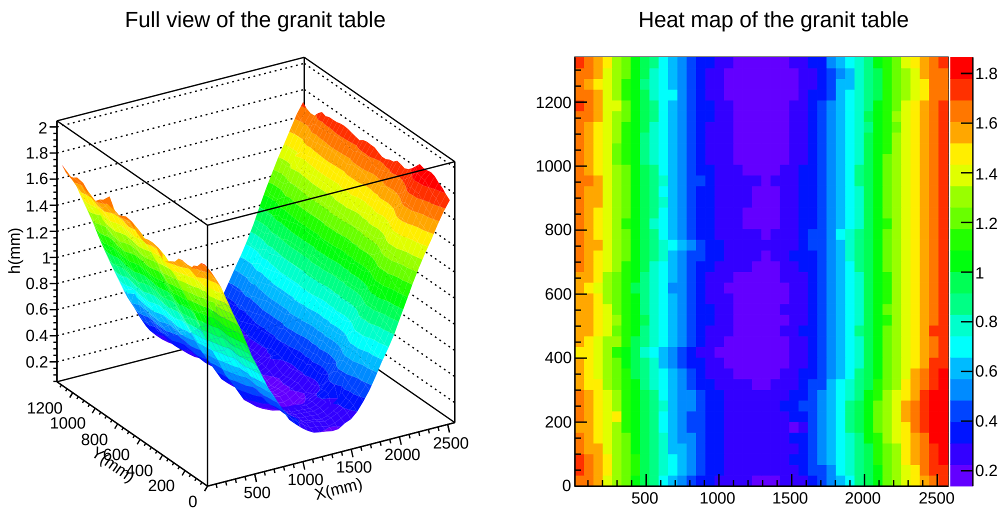


Figure 10: 3D fit and heat map of the granite table.

4 Discussion

The original data sets were not optimal for analysis because of numerous bad points that they had. I analyzed the data and preformed a data selection by removing the bad points. This resulted in data being a better representation of the panels. The new data can be used to find the real points that are not in the required range ($\pm 50 \mu m$) and modify them.

The problem that I had, while making the program with the standard deviation, was the fact that there were set of points that were drastically influencing the average height values, and after I executed the program, not all the bad points were excluded. That is why I used a program beforehand to remove as much of those points as possible. After I included this additional program, the standard deviation program worked more precisely and I got the expected results.

5 Conclusion

The results of this analysis and modifications are data sets that are a better representation of the said granite table and PCB panel. Based on these modifications, the new data sets can be used to remove all the points that are not in required range.

6 Acknowledgments

I would like to thank my supervisor Alexi Gongadze for his help and guidance. Special thank you to Irma Gongadze, Dmitry Dedovich, Rostislav Sotenskii, Irakli Minashvili for this great work experience, their help and wonderful company. Particularly thank you to Lisan David Cabrera Gonzalez for sharing his code which helped me advance with my own problem. I also would like to thank Mrs. Elena Karpova and the rest of the JINR University Center staff for all their help with the administration. Thanks to the JINR, especially the DLNP for this internship opportunity and the funding. Needless to say, I have had an amazing stay in Russia.

7 Appendix A

The data selection was done with the following code.

First part of the program, in which $\sigma_i = \sqrt{var_i/n_i}$ (var stands for variable, n stands for number od points):

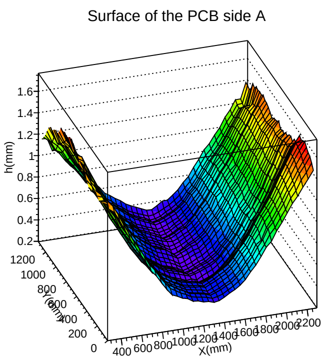
```
while (!file.eof()) {
in2 >> h >> x >> y;
if (h!=0) {
if (x<=325 && y<=625){var1=var1+(h-havg1)*(h-havg1);}
if (x<=325 && y>625 && y<=1250){var2=var2+(h-havg2)*(h-havg2);}
if (x<=325 && y>1250 && y<=1875){var3=var3+(h-havg3)*(h-havg3);}
if (x<=325 && y>1875 && y<=2500){var4=var4+(h-havg4)*(h-havg4);}

if (x>325 && x<=650 && y<=625){var5=var5+(h-havg5)*(h-havg5);}
if (x>325 && x<=650 && y>625 && y<=1250){var6=var6+(h-havg6)*(h-havg6);}
if (x>325 && x<=650 && y>1250 && y<=1875){var7=var7+(h-havg7)*(h-havg7);}
if (x>325 && x<=650 && y>1875 && y<=2500){var8=var8+(h-havg8)*(h-havg8);}
...
```

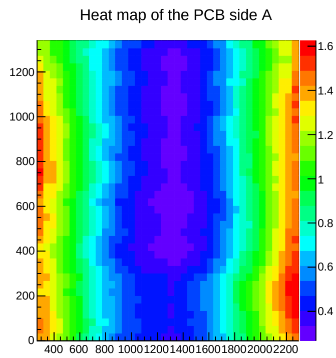
Second part of the program, which is the selection:

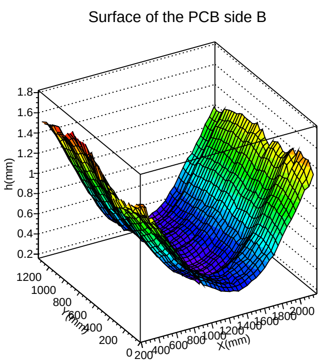
```
while (!file.eof()) {
in3 >> h >> x >> y;
if (h!=0) {
// x<=325
if (x<=325 && y<=625) {
if (h <= havg1+2*sigma1 && h >= havg1-2*sigma1) {
myfile1 << h << "      " << x << "      "<< y << "\n";}
}
if (x<=325 && y>625 && y<=1250) {
if (h <= havg2+2*sigma2 && h >= havg2-2*sigma2) {
myfile1 << h << "      " << x << "      "<< y << "\n";}
}
if (x<=325 && y>1250 && y<=1875) {
if (h <= havg3+2*sigma3 && h >= havg3-2*sigma3) {
myfile1 << h << "      " << x << "      "<< y << "\n";}
}
if (x<=325 && y>1875 && y<=2500) {
if (h <= havg4+2*sigma4 && h >= havg4-2*sigma4) {
myfile1 << h << "      " << x << "      "<< y << "\n";}
} ...
```

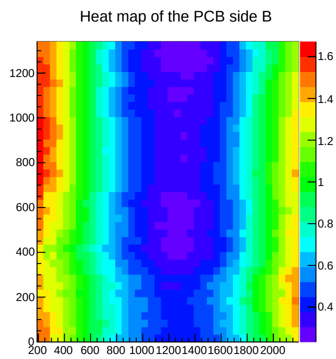
8 Appendix B

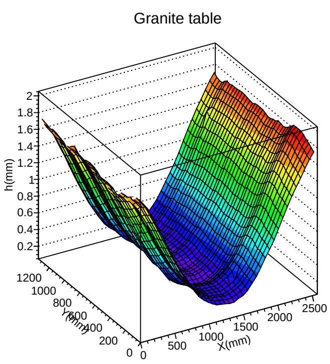
Other figures:

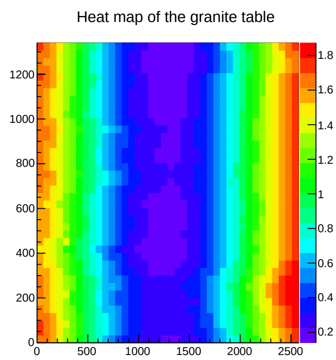












References

[1] A Airapetian, V Dodonov, L Micu, D Axen, V Vinogradov, D Akerman, B Szeless, P Chochula, C Geich-Gimbel, P Schacht, et al. *ATLAS detector and physics performance: Technical Design Report, 2*. Number CERN-LHCC-99-015. ATLAS-TDR-015, 1999.

[2] Rene Brun and Fons Rademakers. Root—an object oriented data analysis framework. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 389(1-2):81–86, 1997.

[3] CERN. The ATLAS experiment. https://atlas.cern/discover/about. [Online; accessed 15-September-2017].

[4] ATLAS MUON Collaboration. New small wheel technical design report. *Tech. Des. Rep. CERNLHCC-2013-006, CERN*, 2013.

[5] P La Rocca and F Riggi. The upgrade programme of the major experiments at the large hadron collider. In *Journal of Physics: Conference Series*, volume 515, page 012012. IOP Publishing, 2014.

[6] Wikipedia. The ATLAS experiment. https://en.wikipedia.org/wiki/ATLAS_experiment. [Online; accessed 15-September-2017].